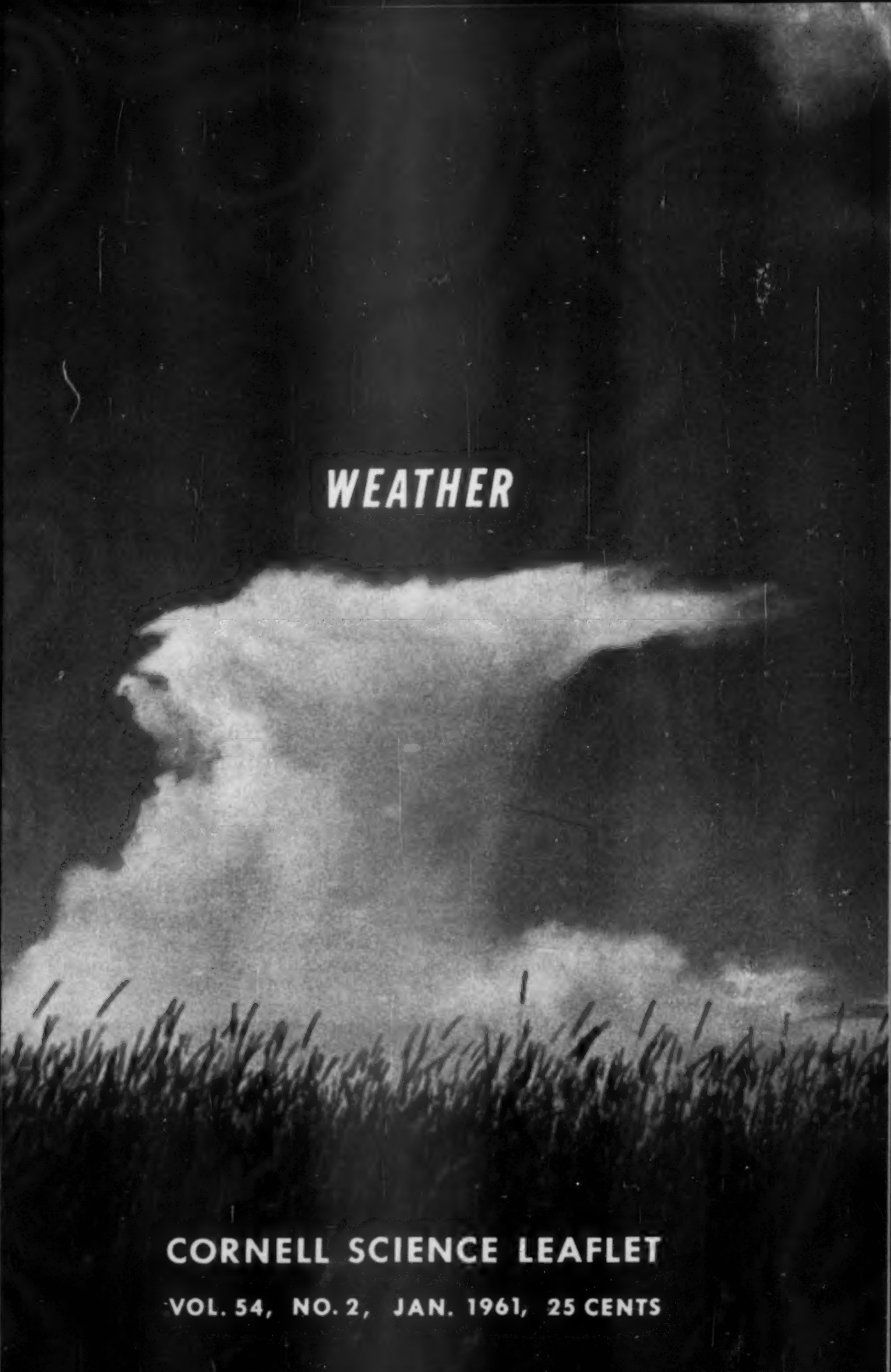

WEATHER

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Cover: A distant thunderstorm is indicated by the spreading anvil top which blows out toward the east.

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WEATHER

Verne N. Rockcastle

Weather can delay a World Series baseball game, it can provide water for bumper crops, or it can produce the snow and ice necessary for successful Olympic Games. Why is the weather so changeable? Can we do anything to make it more reliable? How can we tell what is coming? This Leaflet may help you to answer some of these questions.

The Atmosphere: Our Ocean of Air

The atmosphere extends for several hundred miles above the earth's surface. It is dense (thick) near the ground, but becomes thinner and thinner above the earth's surface until its presence cannot be detected. Just where the top of this air ocean is, no one can tell because there is no known way of measuring air that is so thin. Scientists know there is still some air at a height of about 400 miles, however, because artificial satellites at that height slow a tiny bit with each trip and eventually return to earth.

Our ocean of air may seem very light to you because you cannot feel it pressing on you. However, if you press a plumber's plunger against a smooth surface and force out most of the air underneath it, you will feel this ocean pressing on the plunger. It is difficult to lift the plunger unless some air leaks back under it.

The total weight of the air ocean is 165 thousand trillion trillion tons! The tremendous weight of the ocean of air compresses the air near the ground and makes it much denser than the air near the top of the ocean.

The density of the air decreases so rapidly with altitude that half of all the air surrounding the earth lies within the first four miles above the ground! It is in this bottom, relatively dense layer that most of our weather occurs. Above this bottom layer, the sky loses its blueness, clouds become less frequent, there is no rain or snow, and the temperature hardly changes from day to day.

The Regions of the Atmosphere

The troposphere

The troposphere is the bottom dense region of the air ocean next to the ground. If you could ascend through the troposphere, you would feel the air grow colder as you rose until you reached a level, about five to ten miles above the ground, where the temperature remained constantly cold, or even began to warm a little. This level, the *tropopause,* marks the upper limit of the troposphere.

The troposphere is a moist, unquiet layer, where most of our weather occurs. Most commercial aircraft still fly in the troposphere, although more and more new planes are designed to fly above the troposphere and its weather.

The stratosphere

The *stratosphere* is a frigid, almost cloudless layer above the troposphere. It extends to a height of 20 miles or more above the ground. Its temperature is often below −50°F. It is in the stratosphere that modern long-range planes try to fly because this zone is smooth and free of weather hazards. In the stratosphere, jet aircraft can fly much faster than in the denser, high-friction air of the troposphere.

There is almost no dust in the stratosphere. Because dust and other small particles scatter the blue light from the sun and make the sky look blue, the sky of the dust-free stratosphere looks almost like a night sky.

The warm layer

Above the stratosphere, at a height of about 40 miles, is a *warm layer.* Here the temperature of the air increases to a maximum of about 170°F. Above the warm layer, the temperature decreases again.

The ionosphere

Far above the stratosphere is the *ionosphere,* a quiet layer of thin air. It is the ionosphere that serves as a reflector for most radio waves, and enables us to transmit radio messages around the earth. High in the ionosphere, the temperature increases tremendously, perhaps reaching several hundred degrees Fahrenheit. Above the ionosphere, the air becomes so thin that accurate measurements of its character become difficult or impossible.

The Gases of the Atmosphere

Many gases are to be found in the atmosphere, but only four are important in the troposphere. They are nitrogen, oxygen, carbon-dioxide, and water vapor. Three of these four gases are well mixed, and their proportions remain fairly constant over the earth. Water vapor, however, varies considerably, depending upon temperature and

the availability of water for evaporation.

Water vapor is the most important factor causing weather. Water vapor that leaves the air in the form of rain and snow is constantly replaced by evaporation from oceans and other water surfaces. There is much more water vapor in air over oceans than over land. There is also more water vapor in tropical air than in polar air, because warm air holds more water vapor than cold air does.

If all the water vapor in the atmosphere were condensed to water, it would make a layer about one inch deep over the earth. This may not seem like much water, but it is enough to be largely responsible for clouds, rain, snow, hail, dew, frost, winds, and most other weather characteristics.

The Sun: Earth's Furnace

Although nearly all our weather is caused by water vapor in some form, there would be no water vapor in the air if it were not for energy from the sun. Solar radiation streams to the earth constantly. Even at night, when one side of the earth is in darkness, the other side is in the full glare of the sun.

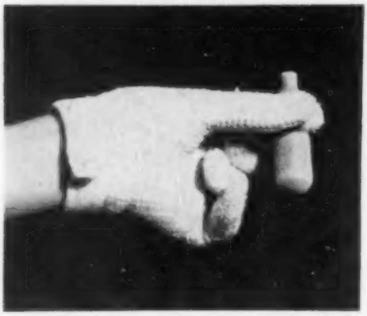
The sun's energy comes to us mostly as invisible, short-wave radiation. Only a part of this radiation helps to heat the earth. As the short-wave energy passes through the atmosphere, some of it strikes clouds, dust particles, smoke particles, and other microscopic flotsam and bounces away.

The energy that finally reaches the ground is absorbed by soil, plants, buildings, lakes, and all other surfaces. Then these warmed surfaces give off their own heat as long-wave radiation which does not pass out through the air as easily as the sun's short-wave radiation comes in. As a result, the sun's energy is trapped in the lower layers of the air. We get warmed just as the plants in a greenhouse get warmed. The lower troposphere may be many degrees warmer than the stratosphere because of the blanketing effect of water vapor and carbon dioxide.

Pressure and Temperature Relationships

Have you ever pumped up a bicycle or an automobile tire and felt the pump grow warm as you worked? Part of the heat was undoubtedly caused by friction, but some of it was caused by the heating of the air as it was compressed. Whenever a gas is compressed, it becomes warmed. Conversely, whenever air (or any gas) expands, it cools.

You can see this for yourself by holding a small carbon dioxide cartridge in a gloved hand while another person punctures the end of the cartridge with a stout needle



A punctured carbon dioxide cartridge will frost over quickly as its temperature drops far below freezing from the reduction in pressure.

and a hammer. As carbon dioxide escapes from the cartridge, frost forms on the outside. This is evidence of the extreme cooling that takes place when the pressure of the gas inside the cartridge is lowered.

In the atmosphere, heating and cooling of the air accompany changes in pressure on the air. Suppose, for example, that some air blows against and over a mountain. As the air rises up the mountain, the pressure on it becomes less. As the pressure drops, the temperature of the air also drops. Going down the lee side of the mountain, the pressure rises. The temperature also rises as the pressure increases.

Sometimes the sun's energy will heat a land surface and the air above it until the air begins to rise. As the heated air rises, its pressure decreases and so does its temperature. When the sun goes down, the heated air may cool until it is colder than the surrounding air. Then it will sink. As it sinks, the pressure on it increases. Its temperature will increase too. In this manner, rising and falling air cools and heats as its pressure changes.

Water Vapor: Weather Maker

The amount of water vapor contained in the air depends upon several factors. Warm water evaporates faster than cold water. Large surfaces evaporate faster than small ones. Warm air can hold more water vapor than cold air.

Relative Humidity

Because water vapor is a key factor in determining kinds of weather, it is important to know how much water vapor is in the air. The amount of water vapor in the air may be expressed in a number of ways, but the most common term is *relative humidity.*

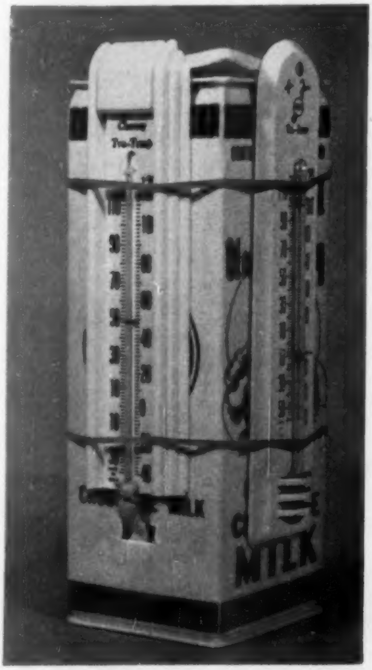
Relative humidity is an expression of the amount of water vapor in the air compared to the maximum that the air could hold. Suppose, for example, that a certain room full of air could hold two gallons of water, but that only one gallon is really present in the air. Its relative humidity would be 50%, because the air holds only half of what it could hold. If the air were holding all the water

vapor that it could, its relative humidity would be 100%. Sometimes rain that forms where the relative humidity is 100% falls through air of which the relative humidity is less than 100%.

Relative humidity can be measured in several ways, but the most common instrument used is the *psychrometer*. To make a simple psychrometer, get two inexpensive thermometers from the five and ten. Remove the bulb guard from one of them. Slip one end of a six-inch length of shoe lace over the exposed bulb and tie it with string or a thread. Cut a hole one inch from the bottom of an empty milk carton, slip the shoe string in this hole, and fasten the two thermometers to the side of the milk carton as shown. Put a half inch of water in the carton. The finished psychrometer will look like that at right.

In the Weather Bureau, a sling psychrometer is used. This consists of two thermometers, one a wet bulb, fastened so they whirl around a handle. You can easily make a sling psychrometer by fastening two thermometers back to back after removing the bulb guard from one of them and attaching a short length of shoe string to the bulb. Tie a cord to the thermometers so they can be whirled, or fasten a short chain and a handle to them for whirling.

The psychrometer makes use of the fact that evaporation is a cooling process. When the shoe lace is wet, water will evaporate from it. The drier the air around the psychrometer, the faster water will evaporate. As evaporation proceeds, the thermometer bulb inside the shoe lace is cooled. The amount of cooling is proportional to the evaporation, which in turn is an indication of the dryness or wetness of the surrounding air.



This simple psychrometer, made from two inexpensive thermometers, can be used to measure relative humidity when used with the table on page 8.

As evaporation proceeds, the water content of the air immediately surrounding the bulb rises. Soon the air around the bulb is saturated, and this layer of saturated air interferes with further evaporation from the wet bulb. For this reason, you should fan the wet bulb continuously, or whirl it, until its temperature is as low as it will go.

When the wet bulb has cooled all it can, read both the wet bulb and the dry bulb temperatures. Look down the left-hand side of the table below until you find the dry bulb temperature of your instrument. Move across the table until you are in the column indicated by the *difference* between the dry and wet bulb temperatures. There you will find the relative

PSYCHROMETRIC TABLE—RELATIVE HUMIDITY IN PERCENT

Dry Bulb Temperature in °F.	Difference Between Dry and Wet Bulb Temperatures														
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
32	89	79	69	59	49	39	30	20	11	2	—	—	—	—	—
34	90	81	71	62	52	43	34	25	16	8	—	—	—	—	—
36	91	82	73	64	55	46	38	29	21	13	—	—	—	—	—
38	91	83	75	66	58	50	42	33	25	17	2	—	—	—	—
40	92	83	75	68	60	52	45	37	29	22	7	—	—	—	—
42	92	85	77	69	62	55	47	40	33	26	12	—	—	—	—
44	93	85	78	71	63	56	49	43	36	30	16	4	—	—	—
46	93	86	79	72	65	58	52	45	49	32	20	8	—	—	—
48	93	86	79	73	66	60	54	47	41	35	25	14	3	—	—
50	93	87	80	74	67	61	55	48	43	38	27	16	5	—	—
52	94	87	81	75	69	63	57	51	46	40	29	19	9	—	—
54	94	88	82	76	70	64	59	53	48	42	32	22	12	3	—
56	94	88	82	76	71	65	60	55	50	44	34	25	16	7	—
58	94	88	83	77	72	66	61	56	51	46	37	27	18	10	—
60	94	89	83	78	73	68	63	58	53	48	39	30	21	13	5
62	94	89	84	79	74	69	64	59	54	50	41	32	24	16	8
64	95	90	84	79	74	70	65	60	56	51	43	34	26	18	11
66	95	90	85	80	75	71	66	61	57	53	44	36	29	21	14
68	95	90	85	80	76	71	67	62	58	54	46	38	31	23	16
70	95	90	86	81	77	72	68	64	59	55	48	40	33	25	19
72	95	91	86	82	77	73	69	65	61	57	49	42	34	28	21
74	95	91	86	82	78	74	69	65	61	58	50	43	36	29	23
76	96	91	87	82	78	74	70	66	62	59	51	44	38	31	25
78	96	91	87	83	79	75	71	67	63	60	53	46	39	33	27
80	96	91	87	83	79	75	72	68	64	61	54	47	41	35	29
82	96	92	88	84	80	76	72	69	65	61	55	48	42	36	30
84	96	92	88	84	80	76	73	69	66	62	56	49	43	37	32
86	96	92	88	84	81	77	73	70	66	63	57	50	44	39	33
88	96	92	88	85	81	77	74	70	67	64	57	51	46	40	35
90	96	92	89	85	81	78	74	71	68	65	58	52	47	41	36
92	96	92	89	85	82	78	75	72	68	65	59	53	48	42	37
94	96	93	89	85	82	79	75	72	69	66	60	54	49	43	38
96	96	93	89	86	82	79	76	73	69	66	61	55	50	44	39
98	96	93	89	86	83	79	76	73	70	67	61	56	50	45	40
100	96	93	89	86	83	80	77	73	70	68	62	56	51	46	41

humidity of the air that you tested.

These relative humidities are based on an atmospheric pressure of 30 inches of mercury. This is average sea level pressure, so if you are above sea level there will be a little error in your measurements. However, this error is small. For all practical purposes, your instrument will help you tell how much moisture is in the air around you.

Condensation in rising air

You know now that when the pressure on air decreases, its temperature also decreases. You know, too, that as air cools its ability to hold water vapor decreases. In air that is rising, the relative humidity increases. If the air keeps rising, the relative humidity also keeps rising until it is 100%. At that point the air is holding all the water it can. *Any further rising usually means that some form of condensation will occur.*

Condensation of water vapor in rising air does not necessarily mean rain, or snow, or hail. It may mean only clouds. If the air keeps rising, however, the clouds may grow larger and larger and the water droplets bigger and bigger until they fall to the ground.

You know that liquid water is heavier than air. Water droplets in air fall toward the ground just as rain falls toward the ground. When cloud droplets are small, they fall slowly. The air around them, however, is rising, because it was rising air that caused the droplets to form. The droplets fall at about the same rate that the air rises, so that the cloud droplets seem to stand still.

If the air in the clouds stops rising and begins to descend, it warms as the pressure on it increases. This warming causes the water droplets in the cloud to evaporate, and the cloud may disappear. This is why cumulus clouds often form in the daytime when the sun's heat causes the warmed air to rise, and dissipate at night when the rising air cools and sinks back to earth.

You can make a cloud form and disappear right in a jar. Put a half cupful of water in a wide-mouthed gallon jar. Cut a piece of rubber balloon or inner tubing to fit over the top of the jar and leave the jar tightly covered for a few minutes until the relative humidity is nearly 100%. Now strike a match or light a cigarette and introduce some smoke in the jar. Quickly replace the rubber covering and tie it securely.

To make a cloud, press down hard on the rubber cover and hold it there for about ten seconds. Quickly release the pressure on the rubber and pull up on it instead. Can you see a sudden fog form in the jar? Push down on the rubber and the fog will disappear. Pull up suddenly, and it will reappear. You can repeat this pulling and pushing

To make a cloud in a jar, put a little water in it, then a little smoke, and push down on the rubber. When you pull the rubber up, a cloud suddenly will appear.

many times and the fog will appear and disappear as often as you do it.

Moutain rain-ges. Air blowing from the Pacific Ocean toward the mountains of the West has a high relative humidity when it strikes the coast. A cool coastal current flows slowly down along the coast from the Aleutians. This coastal water may cool the Pacific air crossing it and form fog along the shore. The fog itself provides little

water along the coast. When the moist air strikes coastal or inland mountain ranges, however, it rises, cools, and produces rainfall in copious amounts. Heavy rainfalls often occur on the western slopes of mountain ranges.

When this air finally gets over the mountain tops, it descends to the flat land on the eastern side. The descending air heats, the humidity drops, the skies clear, and an entirely different climate is found. Denver, for example, has only about 14 inches of rainfall a year, but the western slopes of the Olympic Mountains in Washington get over 100 inches of rain a year!

A similar condition can be found in New York State. Air moving from the west across Lake Ontario strikes a gently sloping land area just east of the lake. This land rises only slightly for about ten miles, then rises more sharply to a plateau that is about 2,000 feet above sea level. This is a rise of over 1,000 feet for the moist air coming from the lake. As a result, the annual precipitation at Batavia or at Lockport, which are on the lake plain, is only a little more than 30 inches. At Highmarket, however, which is on the Tug Hill Plateau east of Lake Ontario, the annual precipitation averages more than 50 inches. Fifty inches more snow falls at Highmarket than at Batavia.

Throughout the Adirondack mountains, the annual precipitation is generally greater than in the lower lands surrounding the mountains. Much of the Lake Ontario coast has an annual snowfall of about 70 inches. The western Adirondack slopes, however, get more than 140 inches of snowfall annually.

In Chile, the western slopes of the Andes may have as much as 100 inches of rainfall from the humid ocean air blowing against them. On the east side of these same mountains, however, are deserts where as little as 0.12 inches of rainfall has been recorded in a six-year period!

In India, there is a famous mountain station where the greatest rainfall in the world occurs. Moist air blowing from the Indian Ocean against the Himalayas drops almost unbelievable amounts of rain on the southern slopes. At Cherrapunji in northern India, a steady moist breeze from the Indian Ocean can cause as much as 400 inches of rain in a single six-month period!

Convection. Mountains are not the only cause of rising air. Air may be heated by the sun, and rise. It may pass over a warm land or water surface and rise because it is warmed from below. It may rise over a mass of cold air that acts as a mountain range. It may be forced to rise because it is squeezed by air pushing on either side. It may also rise if it is over a water surface for

a long time, because moist air is lighter than dry air.

Does it seem odd that moist air should be lighter than dry air? At a given pressure and temperature, a space can contain only a certain number of gas molecules, no matter what gas occupies the space. If a cubic foot space contains only oxygen, nitrogen and carbon dioxide, it contains molecules whose relative (molecular) weights are as follows (considering a hydrogen atom to be 1.00):

nitrogen	N_2	$14 + 14$	$= 28$
oxygen	O_2	$16 + 16$	$= 32$
carbon dioxide	CO_2	$12 + 16 + 16$	$= 44$

A molecule of water vapor (H_2O), however, has a molecular weight of only $1 + 1 + 16$, or 18. This molecule is lighter than nitrogen (28), oxygen (32), or carbon dioxide (44). When a molecule of water vapor enters the air, it replaces one of the heavier molecules and makes the air lighter. By picking up water vapor, air actually becomes lighter.

When the sun warms a land surface, the air next to the land is heated, and the heated air rises. As it rises, it cools, and if the air continues to rise, condensation will occur. This condensation will be in the form of water droplets or ice crystals. As each droplet or ice crystal forms, it gives back to the air some heat that was needed to evaporate the water when it went into the air. This heat, called the heat of vaporization, warms the air in which condensation is taking place.

If great quantities of water vapor condense, the heat given back to the air may be enough to speed up the rising air and thus cause even more condensation. The greater condensation may cause more heat, and this in turn cause the air to rise still faster. A kind of chain reaction may form from a mass of air rising because of the sun's heat. Thunderstorms grow in this manner.

Condensation without lifting

Water vapor may condense from the air without being lifted at all. Surfaces such as rooftops, grass, soil, water, auto tops, and even our own bodies radiate heat all the time. From our heads, heat energy radiates toward the sky. Roofs radiate toward the sky, as do car tops and soil. The side of a building, however, radiates sideways. So do our legs and arms, the trunk of a tree, and the side of a steep hill. During sunlit hours, the incoming heat from the sun is greater than the heat that radiates from objects on the earth. This warms the earth's surface and the objects on it.

During the night, however, objects on the earth radiate their heat outward, but do not receive heat from the sun in return. This cools surfaces such as rooftops, soil, auto tops, leaves, and sidewalks.

The sides of buildings and automobiles, however, get heat from the sides of other objects that radiate toward them, so they do not cool as much as the roof.

As a sidewalk radiates its heat out to space, more heat flows into the concrete from the soil beneath it. The temperature of the sidewalk and most other pavements drops only slightly.

A board lying on the ground, however, is a poor conductor of heat. When its upper surface radiates heat toward the night sky, little of the heat from the ground under the board replaces what is lost. The upper surface continues to cool in spite of the fact that the soil beneath the board contains a quantity of heat. The upper surface of the board becomes much colder than the upper surface of the pavement.

Fog: cloud on the ground

Radiation Fog. Besides radiating from soil and vegetation, heat also radiates from the dense air at the earth's surface. As the air next to the ground cools, it becomes heavy and flows downhill. It may puddle in the low spots such as valleys and hollows, where it cools still further until dew and fog form. This shallow fog forms when skies are clear, and the air is moist and calm.

Steam Fog. On very cold winter mornings, fog sometimes forms over water in very dense patches or layers. It also forms over ponds and lakes on clear summer nights. Fog that forms over water during a summer night, or during a very cold spell in winter, is called steam fog. It forms only when the water is much warmer than the air above it. The warm water evaporates into the shallow layer of warmed air above it, then almost immediately condenses again when the warm layer of air rises and mixes with the cold air.

On clear nights in the Adirondacks and other mountainous or hilly areas, cold air often collects over lakes and ponds that warmed to 75° or 80° F. during the day. The air over these bodies of water continues to cool rapidly as heat radiates out to space. The water, however, cools much more slowly, so that by evening or early morning a layer of fog hangs over the lake. Soon after sunrise, when this foggy layer becomes warmed, the water droplets evaporate and the fog disappears.

Advection Fog. In some parts of the country there are cold water currents that do not warm up in summer. One of these is the Labrador Current that flows south along the northeastern coast of the United States. Another is the Aleutian Current that flows south along the coast of northwestern United States. In summer these coastal waters may be 30° F. cooler than the air passing over them.

When warm, moist air passes over these cool ocean currents, it is

On the day that this steam fog occurred, the air temperature was 1°F., and the water was 35°F.

Steam fog formed over this pond when the water temperature was 75°F., and the air temperature was only 53°F.

cooled from below. If the cooling is sufficient, fog forms. Advection fog usually is more persistent and deeper than radiation fog.

Frontal Fog. This fog is formed ahead of a warm front (see page 27). It is caused by warm rain falling through colder air below. When the rain enters the cold air, part of the rain evaporates into the air immediately surrounding the drops, then condenses again as this moist air mixes with the colder air around it.

Clouds

Only water in its liquid or solid state forms clouds. Water vapor itself is invisible. You cannot see water unless it is condensed. Clouds represent condensation from moist air that has cooled, usually by rising.

Some clouds are dark, while others are light colored. Dark clouds are thick clouds. When a cloud is so tall that little light penetrates it, the base of the cloud is dark. Clouds may also appear dark because they are shaded by other clouds above them.

Low clouds are almost always water droplet clouds. High clouds, or clouds formed where the temperature is far below freezing, are often made of icy crystals. Both high and low clouds may be present in the sky at the same time. At sunset or sunrise, you can often see clouds at more than one level. The sun continues to illuminate the highest clouds even after it has set on the lower ones.

Cumulus clouds. These are puffy clouds of water droplets. When they are small, they represent fair weather. They form when the air is heated unequally and parts of it rise while other parts descend. If you could fly through a cumulus cloud, you would feel the plane suddenly lift you as it entered the cloud. As you left the cloud, you would suddenly drop. When cumulus clouds are in the sky, you may be sure that the air is unsteady or turbulent.

If the heating of the air is strong and there is plenty of moisture, cumulus clouds may grow and become *swelling cumulus.* These are rounded and puffy on top, but they are huge clouds that may cover several square miles. Sometimes brief showers occur under swelling cumulus clouds.

If swelling cumulus clouds continue to rise because of heating and moisture, they become *cumulonimbus* (thunderstorms). You can recognize a cumulonimbus because it is flat on top (see the cover picture). This happens when the rising air currents reach the tropopause and stop because the rising air is no longer warmer than the surrounding air. Then the top of the cloud spreads sideways. This spreading portion of a cumulonimbus is called an *anvil.*

The temperature near the top of a cumulonimbus cloud is so low

that the anvil is made of ice crystals. It is really a cirrus top on a water-droplet cloud.

Weathermen used to think that cumulonimbus clouds reached a maximum of about 50,000 feet, but recent high altitude observations showed some cumulonimbus attaining heights of 70,000 feet! To rise to this height clouds require convection of severe intensity. The severity of the vertical currents in a big cumulonimbus can tear the wings from an airplane that flies too fast through the cloud. Think what a stress it must be for a plane to experience a sudden updraft of 60 miles per hour when flying at a speed of 200 miles an hour, or more. Reducing forward speed reduces the suddenness of the updraft and also the stress on the plane.

The forward half of a cumulonimbus is the more severe. It is preceded by a downdraft that is often felt several miles in advance of the storm. This downdraft is caused by the cooling effect of rain and hail on the air beneath the storm.

Following the downdraft, heavy rains often fall from the forward half of the storm. These may be accompanied by strong gusts of wind that occasionally reach hurricane force. Fortunately, these gusts usually do not last for more than a few seconds.

It is in the heavy rain portion of the storm that hail occurs. Hail is the result of raindrops being carried aloft by severe updrafts and frozen. After being carried up and down several times, they accumulate successive shells of ice that you can see for yourself by cutting a hailstone in half and examining it under a magnifier. Hail is one of the greatest dangers for aircraft in a severe thunderstorm. It can also ruin crops by pelting them to pieces. One of the largest hailstones to fall in the United States fell in Nebraska in 1928. It weighed 1½ pounds and was 17 inches in circumference!

The causes of lightning still are not well understood The heat produced by a lightning flash, however, causes a sudden expansion of the air along the stroke. This sudden expansion is like an explosion that echoes among the clouds and the surrounding terrain. Thunder cannot be heard for more than about 15 miles, however, and distant thunderstorms are only silent flashes of light. Some persons call this "heat lightning," but it is only visible evidence of a storm too far away to be heard.

In the preceding Leaflet, *Sound,* a method of plotting the path of thunderstorms is described. You may wish to try this with a single storm to see how fast it moves, and in which direction it goes.

As you study cumulonimbus clouds, you will not only lose your fear of them, but you will also find them one of the most fascinating

features of the fluid forces that frustrate forecasters.

Altocumulus and *altostratus* clouds are called middle clouds because they form at a level between cumulus clouds and cirrus clouds. When present, altocumulus and altostratus clouds are usually from 8,000 to 15,000 feet above the ground. When altostratus clouds cover the sky, they cause a ring around the sun or moon. This ring is a corona. A corona around the sun or the moon often signals the approach of a rainy day or night. A common but untrue belief is that the number of stars inside the corona indicates the number of days before it will rain.

Cirrus clouds, *cirrocumulus* clouds, and *cirrostratus* clouds are all formed from ice crystals. They are very high clouds — usually above 20,000 feet. In the tropics, cirrus clouds may form as high as 50,000 feet when they are part of a cumulonimbus cloud. At our latitudes, cirrus clouds are not often more than 35,000 feet above the ground.

When cirrus clouds cover the sky, they also cause a ring around the sun or moon. This ring, called a halo, is larger than the corona caused by altostratus clouds because ice crystals refract light more than water droplets. As with a corona, the number of stars inside the halo is no indication of the number of days before rain. Cirrus clouds, however, do give earlier warning of approaching rain than do altostratus clouds.

The United States Weather Bureau has published an excellent *Cloud Code Chart* with symbols and brief explanations of their significance. You can get this by sending 10 cents to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. For 30 cents, you can get a more complete *Manual of Cloud Forms and Codes for States of the Sky.* Study the clouds and learn to recognize them. Although it is difficult to make rules about the weather that follows certain cloud formations, you can learn to associate the major cloud types with the approaching weather for your own locality.

Pressure

Many years ago it was recognized that pressure changes accompany changes in the weather, and often can be used to help predict the weather. The atmospheric pressure at any spot on the earth is the pressure exerted by the air above that spot. If you could weigh a column of air touching one square inch of the earth's surface and extending up 500 miles (the approximate depth of our ocean of air), it would weigh about 14.7 pounds at sea level. Sometimes it would weigh as little as 14 pounds, and at other times, it would weigh almost 15½ pounds. If the column of air were

warm, it would not weigh as much as if it were cold. If it were moist, it would not weigh as much as if it were dry. Many things affect the weight of the air above the earth.

Suppose you were to use a barometer to measure the air pressure at New York City, Buffalo, Chicago, Pittsburgh, Denver, and Minneapolis. Because Denver is the highest of all these cities, there is less air above Denver than almost any other major city in the United States. The air pressure there would be only about $^5/_6$ of what it would be at New York City. The air pressure measured at Denver is always so low that it might seem as if bad weather is always in store for the city. (The pressure at Denver usually is lower than in the center of a hurricane!)

You can see that the pressure at Denver and at New York City can be compared only at the same altitude. When weathermen compare pressure at one weather station with another, they compare *corrected* pressure. Depending upon the altitude and temperature, they add a certain amount to the pressure of any station above sea level. If Denver's temperature were low, a greater correction would be made than if it were high. After the observed pressure is corrected for altitude, the pressure can be compared to any other station whose pressure has also been corrected for altitude. When you hear atmospheric pressures quoted on the radio, or see them in the newspaper, they are corrected pressures. Observed pressures are meaningless until they are corrected for the altitude of the station.

The barometer

A barometer is used to measure air pressure. Two kinds of barometers are in common use. The more common kind is the *aneroid* barometer. This instrument has an accordion-like metal box that is partially emptied of air and sealed. This metal box expands a little when the air pressure is low and contracts a little when the air pressure is high. Its contractions and expansions move a series of levers which, in turn, rotate a pointer on a dial. Good quality aneroid barometers are corrected for variations in temperature, but some of the inferior ones vary slightly as the air temperature changes.

Some science books show a simple aneroid barometer made from a milk bottle, a rubber sheet across the opening, and a soda straw glued to the rubber. This kind of aneroid barometer is not a satisfactory indicator of pressure changes, however, because temperature affects it too. A more satisfactory aneroid barometer can be made from a small vial, a six-inch piece of slender glass tubing, a one-holed stopper for the vial, and a wide-mouthed gallon jar. Insert the glass tubing in the stopper, and put the stopper in the vial. Fill the

gallon jar nearly full of water. Warm the vial slightly in your hand, then drop it into the jar of water. The glass tubing will point down, and water will rise a little way in it. When the vial is the same temperature as the water, the water will stop rising in the glass tube. Increasing air pressure will make the water rise slightly in the tube. Decreasing pressure will make it fall. A scale fastened to the side of the glass tube will help you read the water level.

This type of aneroid barometer is also subject to error because of temperature changes. The gallon of water around the vial, however, tends to keep the temperature constant. There is far less error in this barometer than in one made from a milk bottle and soda straw.

The other kind of barometer is the *mercurial* barometer. It consists of a vertical glass tube, closed at the upper end and filled with mercury. You can make a fairly good mercurial barometer by sealing one end of a glass tube about 33 inches long. Fill the tube with mercury after you have sealed the end. Jar the tube slightly to make sure that no air bubbles remain in the tube after it is filled. Now hold a finger over the open end, invert the tube, and submerge the unsealed end in a small dish of mercury. Remove your finger. The mercury will drop a short way in the tube, bounce up and down a few times, and finally remain at a certain level. Arrange a sturdy support for the vertical tube, and you have a workable mercurial barometer.

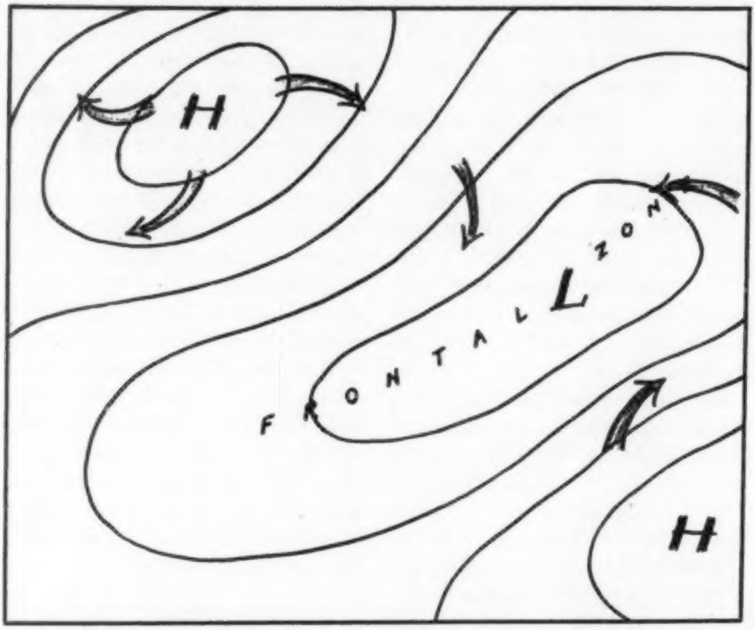
To measure air pressure with your barometer, measure the distance from the top of the mercury in the dish to the top of the mercury in the tube. You can measure the pressure in inches or in centimeters of mercury. Most weathermen measure it in inches or in millibars. (One inch of mercury is equivalent to 33.86 millibars.)

Your barometer is good only for telling how the pressure is changing. Use it to compare pressure changes from day to day at one place, not to compare its pressure with that in another city or town for which pressure reports have been corrected.

Wind: Air in Motion

When the pressure at one place is different from the pressure at a nearby place, air will flow from the higher to the lower pressure and create wind. When the pressure difference between two places is greatest, wind between them will be the highest. When the pressure changes very little or none at all between two places, then the wind is light or calm.

Because the earth is rotating, winds do not blow directly from high to low pressure areas. Instead, they are deflected toward the right in the northern hemisphere and to the left in the south-



ern hemisphere until they almost circle the pressure centers. In the figure above a high and a low pressure area are sketched, with air moving from the high toward the low. No matter in what direction the air leaves the high pressure center and moves outward from it, it is deflected to the right. This causes a clockwise rotation of the air moving out of the high center.

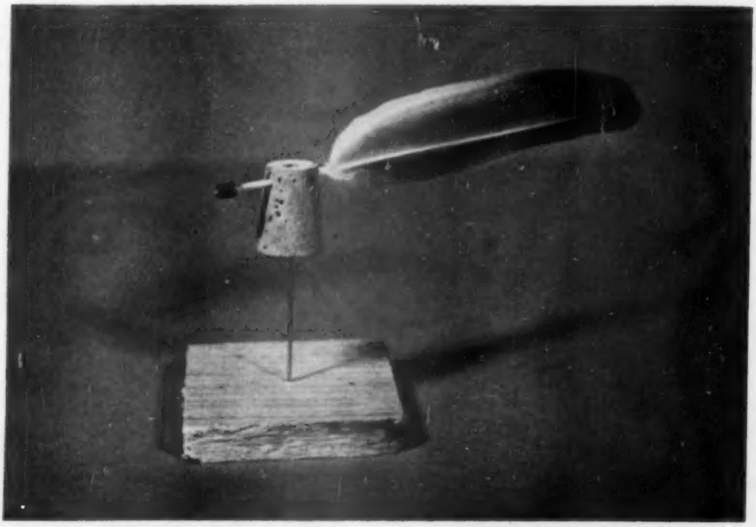
In the same manner, air moving into the low center from higher pressure around it soon rotates counter-clockwise. All lows in the northern hemisphere rotate counter-clockwise soon after air begins to flow into them. Just as water running down a washbowl drain often spins and slows the rate at which the bowl empties, lows spin and hence take longer to "fill up."

If you put your hand in the water of an emptying bowl, it will slow the spinning and hasten the emptying. In a similar manner, mountains, hills, trees, buildings, and other obstacles on the earth's surface provide friction for the air circling a low center. When the friction is great, the air moves into the low center more rapidly. Above water, however, friction is nearly absent. Low centers over water may persist for days because air moves very slowly into the low center.

Wind direction

Wind direction is measured by a *wind vane*. The wind direction is always the direction *from which* the wind blows. A north wind blows from the north. A south wind blows from the south. You can make a sensitive weather vane from a pigeon feather, a cork, a short length of glass tubing, and a needle. Seal over one end of the glass tubing by rotating it evenly and constantly in a flame as shown. With a small triangular file, make a notch in the tubing about an inch from the seal, turn the notch away from you, and carefully break the tubing.

To make a good seal, rotate the tubing constantly while it is in the flame.



The glass tubing in the cork makes an ideal bearing on which this sensitive weather-vane turns.

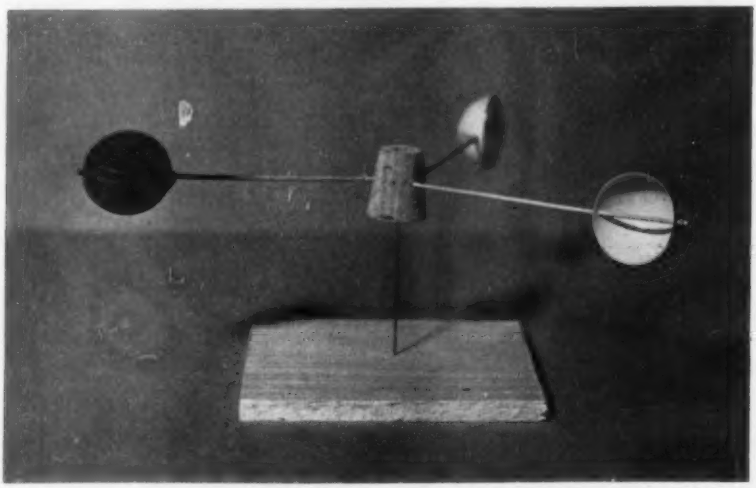
Bore a hole through the cork from large end to small, making the hole just the size of the tubing, or slightly smaller. Insert the sealed end of the piece of tubing in the large end of the cork. Fire polish the cut end of the tubing by holding it in the flame for a few seconds. Let the glass cool.

Make another, smaller hole across the small end of the cork. In this hole insert the feather. Push the glass tubing into the cork until it stops at the feather shaft. Set this feather vane on a needle point and you will have a very sensitive wind direction indicator. Remember that the feather points in the direction from which the wind blows.

Wind speed

An anemometer is an instrument used to tell wind speed. Some anemometers are whirling cups that spin in the wind. Commercial anemometers generate a tiny bit of electricity that moves a pointer on a dial some distance away.

You can make a simple rotating cup anemometer by using ping pong balls and swab sticks, together with a cork and glass bearing as described on page 21. After the bearing is in the cork, insert three swab sticks at equal distances around the large end of the cork. Cut two ping pong balls in half, using either a coping saw or scissors. Drill a tiny hole through



A glass bearing similar to that described on page 21 is ideal for use in this ping-pong ball anemometer.

three ping pong ball halves near the cut edge. Insert the swab sticks and fasten the cups in place with rubber bands as shown. Paint one of the balls to make it easier to count the number of turns of the anemometer.

To calibrate your instrument, ask a friend or parent to drive you along a road on a calm day. At five miles per hour, count the number of times your anemometer turns in a given time such as a half-minute. Then count the turns at 10 miles per hour, 15 miles per hour, 20 miles per hour, and so on. Keep this record. It will be your calibration chart.

After you have calibrated your instrument, you can hold it in the wind, count the number of turns in half a minute, then consult your calibration chart to see how many miles per hour is equivalent to your count. You may even wish to make a graph of miles per hour *versus* number of turns in a half minute. This will provide you with a calibration curve from which you can find the wind speed after counting the turns your instrument makes in a half minute.

Keep a record of wind speed and direction, as well as a record of air pressure. You may find that rain usually follows an east wind and a falling barometer, or that a cold night will follow a northwest wind and a rising barometer. By keeping a good record, you will be able to interpret combinations of wind direction and pressure changes for your own locality.

Precipitation

To record rainfall, a rain gauge is used. Because rainfalls in the Northeast do not often exceed $\frac{1}{2}$ inch, and are frequently less than $\frac{1}{4}$ inch, it is necessary to measure these small amounts carefully to avoid error. If in measuring a rainfall of $\frac{1}{8}$ inch, you made an error in measurement of only $^{1}/_{16}$ inch, you would be making a 50% error!

To make your own raingauge, get a number five can, a small juice can, and a funnel whose top is at least as large as the number five can. Use the funnel to send rainfall into a smaller container where it is deeper and more accurately measured. Measure the diameter of the funnel and the top of the small can. Square these two numbers. This gives the ratio of the areas of these two openings.

Suppose you ratio comes out to be 4:1 for funnel to can. On a small stick measure off four inches and label this "1." At the two-inch mark, label "$\frac{1}{2}$." At the one-inch mark, label "$\frac{1}{4}$." This is your calibration stick. Since the depth of the water collected in the small can will be magnified four times (because the area of the funnel is four times the area of the small can), the stick is calibrated accordingly. When you measure water that is two inches deep in the small can,

your stick will tell you that only ½ inch of rain has fallen.

Source Regions and Air Masses

In some parts of the world such as the Caribbean Sea, northern Canada, the Sahara Desert, Siberia, the northern Pacific Ocean and the northern Atlantic Ocean, air often remains for several days until it assumes some of the characteristics of the surface beneath it. In northern Canada, the air becomes cold and dry. Over the Caribbean, it becomes warm and moist. Over the Sahara it becomes hot and dry. Large surfaces that influence the air over them are called *source regions*. From them pour masses of air from time to time, and these masses have a pronounced effect on local weather.

Continental polar (cP) air

Northern Canada is the source region for much of the air that moves over New York State, especially during fall, winter, and early spring. This air, called cP air by weathermen, is usually cold, dry, and free from haze. It contains little moisture because there is no extensive water area to evaporate into the air when it is in Canada. In winter, its temperature falls only slightly with height because the surface air is already cold.

When cP air comes to New York State, some important changes take place. When it crosses the Great Lakes, especially in winter, the cold surface air becomes heated strongly by the water. The air also picks up considerable moisture at the surface of the lakes. The heating and the moisture combine to produce heavy stratocumulus clouds from which come frequent snow flurries. Sometimes these snow flurries are severe, blanketing towns and cities along the southern lake shores with many inches of snow, while further south the weather is clear and cold. Winter nights in cP air are crystal clear and crunchy cold.

In summer, cP air means fine weather. Visibilities may range up to more than 100 miles. Daytime temperatures are comfortably warm, and nights are pleasantly cool.

Maritime tropical (mT) air

When a mass of air from the Caribbean Sea moves northward over New York State, we have warm, muggy, showery weather. In summer, thunderstorms are common in mT air. Temperatures may soar into the 80's and 90's accompanied by high humidity. Haze usually is present in mT air, reducing visibility to a few miles. Cirrus, altostratus and altocumulus, and towering cumulus clouds are often present in varying amounts. Nights are seldom free of clouds. In winter, our thaws come with mT air.

Maritime polar (mP) air

Maritime Polar air occasionally may invade eastern United States. If it comes from the west, it must cross the mountain ranges in order to enter mid-country. Although it has a high moisture content and is rather cool when it enters the country, the mountains force out copious amounts of rainfall so that its moisture content is much reduced. This also raises its temperature, because condensation releases much heat to the air around it. By the time mP air reaches New York State, it brings warm, dry, and generally fine weather.

Maritime polar air from the east, however, does not cross extensive, high mountains before flowing into central New York State. It comes to us as moist, cool air that can drop large amounts of rain and snow. A few of the "nor'easters" that ravage the New England coast are caused by mP air. The rest are the result of mT air moving northward.

These three air masses affect New York State weather in the following way:

Air mass	Comes from	The weather it brings	
		Summer	*Winter*
cP	north	fine, cool	snowy, cold
mT	south	muggy, hot	thaw
mP (Pacific)	west	clear, warm	clear, cool
mP (Atlantic)	east	rainy, cool	rainy or snowy, cool

Remember that these air masses may affect other areas of the country in a different way.

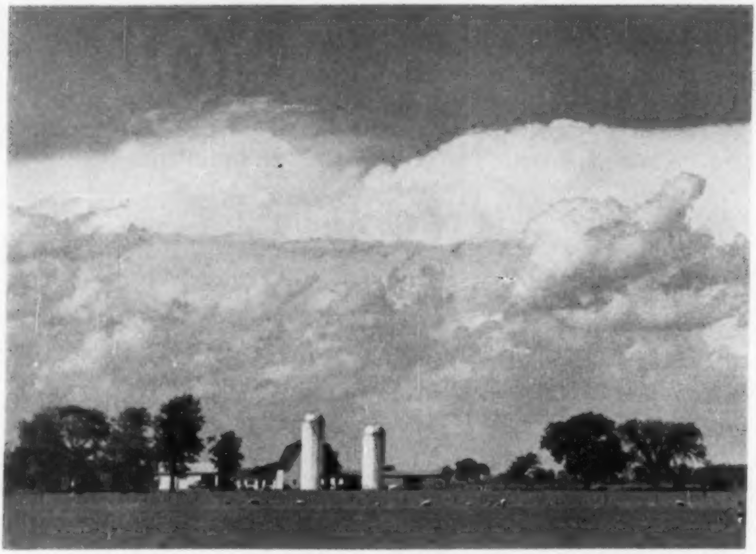
Fronts: Clashes of the Masses

What is a front?

The ocean of air that covers the earth is always in motion, even though at times it may seem to be still. From time to time, surges of the air ocean over Canada, or over the Caribbean, send cold or warm air into the eastern United States. Where one of these surges of cold or warm air meets another air mass, a *front* is formed. A front is the boundary between two unlike masses of air. Sometimes the boundary is distinct, with contrasting temperatures, winds and weather within a few miles. At other times, the boundary is so indistinct that it is difficult to locate. When two different air masses first meet each other, the boundary is well defined. Like any liquid, however, air mixes freely, and after a few days the boundary often becomes obscure.

Cold front

If the cP air moving southeastward from Canada pushes over the ground, forcing up or aside the air in its way, its advancing edge is called a *cold front*. Imagine that a cold mass of air lies to the north of your home, and that you are taking a drive northward toward the air mass. You start out in mild air



This remarkable bank of cumulus clouds marks the approaching edge of a severe cold front that dropped the temperature nearly 20°F. when it passed.

with plenty of moisture and sunny skies. As you approach the cold front, you notice cumulus clouds being formed ahead of you. The wind seems to be a little stronger from the south, and your barometer is falling. Then you drive through the front into the cold air. Around you the temperature falls, some rain or snow also falls, and your barometer begins to rise. As you travel north, the precipitation becomes lighter, the clouds higher, and finally skies are clear again.

If you turn around and travel home again, you will encounter the same conditions in reverse order. Clouds thicken and darken. The barometer falls. Light rain or snow increases in amount as you approach the front that marks the boundary between air masses. As you drive through the front, the temperature rises, the precipitation tapers off into showers, the wind shifts to south, the barometer begins to rise, and the sun finally shines again.

Most cold fronts in eastern United States move from the west or northwest. The front itself usually lies in a northeast-southwest direc-

tion, with cold air to the northwest, and warm air to the southeast.

When a mass of cold air moves across the ground, the friction from trees, hills, buildings, and other irregularities makes the surface air lag just a little behind the upper air. This makes a cold front a little steeper than a warm front. The steeper front makes the weather more violent at a cold front than at a warm front. Precipitation tends to be more showery than steady; winds shift more strongly and quickly; and the barometer falls and rises more abruptly during the frontal passage.

Cold fronts signal the arrival of "blizzards" or "cold snaps" in winter. A blizzard results from high winds, low temperatures and snow. Often the amount of snowfall is not high, but the winds whip the snow into deep drifts that may isolate communities, tie up highway traffic, or stall trains not equipped to travel in the snow.

In summer, cold fronts are often followed by clear, pleasantly cool weather with high visibilities and little or no rainfall.

Warm front

When a surge of mT air from the Caribbean causes a retreat of the cooler air to the north, the advancing edge of the warm air is a *warm front*. As it advances, warm air slides up and over the retreating cool air, bringing cloudiness and steady precipitation ahead of the frontal surface. Because surface friction holds back the advancing air, the warm front is a more gentle slope than the cold front, and the weather changes at the front are not so severe.

At a city or town in the cool air ahead of the approaching warm front, the barometer drops slowly, clouds thicken from cirrus to altostratus, and finally light rain begins to fall. The rain increases as the front approaches. Winds increase in speed from the east.

As the front passes, the wind shifts to the south, the temperature rises, the clouds break up, and a slow rise in pressure accompanies the sunshine. Warm fronts in winter signal an approaching thaw. Often these thaws are followed by a cold front with its attendant snow flurries and dropping temperatures. In summer, a warm frontal passage usually brings hot, muggy air, with afternoon thunderstorms and uncomfortable nights.

The summary on page 29 may help you to determine which of the two kinds of fronts is approaching you.

Cold fronts usually move more rapidly than warm fronts, and often catch up with them. When they overtake warm fronts, an *occluded* front is formed. You can read more about these occluded fronts in some of the references at the back of this Leaflet. They combine many of the characteristics of

Low-hanging clouds with drizzle and showers may make the day dark, wet, and dreary just ahead of a warm front.

both kinds of fronts. Sometimes the weather associated with them is severe, even though their surface characteristics are not so pronounced as warm or cold fronts. Strong occluded fronts are more common in winter than in summer.

Weather Maps

In order to help forecasters see and predict the weather across the nation, weather maps are drawn every six hours. A few years ago, each major weather station had a person whose job it was to draw and analyze weather maps. Today machines make facsimile weather maps from a master map drawn by an expert, usually at the U. S. Weather Bureau Office in Washington, D. C. At most major weather centers, these machines turn out electrically drawn facsimiles of the original map from the Weather Bureau.

On a standard weather map, data from selected stations all over the country are shown in symbolic form. Each station model or symbol shows the clouds, wind, pressure,

BRIEF SUMMARY OF FRONTAL WEATHER

	Ahead of Cold Front	Ahead of Warm Front
Where you are:	In warm air	In cold air
Pressure:	Falling rapidly	Falling steadily
Temperature:	Warm	Cool or cold
Wind:	Strong southwesterly	Easterly
Clouds:	Altocumulus, some cumulus	Altostratus becoming nimbostratus
Weather:	Swelling cumulus, showers	Steady rain or snow
	Passing Cold Front	**Passing Warm Front**
Where you are:	In frontal zone	In frontal zone
Pressure:	At lowest point	At lowest point
Temperature:	Beginning to drop	Beginning to rise
Wind:	Shifting, gusty south to west	Shifting east to south
Clouds:	Cumulonimbus or stratocumulus	Nimbostratus, cumulonimbus
Weather:	Heavy, brief showers, gusty	Heavy rain or snow, sometimes fog
	Behind Cold Front	**Behind Warm Front**
Where you are:	In cold air	In warm air
Pressure:	Rising rapidly	Rising slowly
Temperature:	Falling rapidly	Becoming warm
Wind:	Strong from northwest	South
Clouds:	Stratocumulus, clearing	Scattered cumulus, hazy
Weather:	Snow flurries, or rain, then clear, cold	Warm, humid, occasional precipitation

temperature, dewpoint, barometric change, and precipitation. With this information for each station, the forecaster locates highs, lows, fronts, and areas of precipitation. When the map is completed, he compares the newest map with preceding maps to find out how fast the pressure centers and the fronts are moving, and whether they are growing stronger or weaker.

The process by which much local forecasting is done is *extrapolation*. That means projecting a trend into the future. Suppose you were given the numbers 2, 4, 6, 8, and 10, and were asked to give the next number. You would say 12, of course. You have extrapolated on the basis of what you knew about the preceding data. That was easy.

Suppose, however, you were given the numbers, 3, 7, 12, 18, and 25. What would be your guess for the next number? In this case, you could see that the numbers were increasing by an increasing amount, so you would take this into account in your extrapolation. A forecaster does much the same. When he sees that a high pressure center is moving steadily at 50 miles per hour toward the southeast, but is weakening, he projects it still farther southeast, and forecasts its pressure to drop still more. Forecasting is not quite this simple, but extrapolation is still the basis for much of the short-range forecasts made by your local weather station.

To become familiar with weather maps and what they can tell you, study them each day. Small weather maps are printed in most daily newspapers. Better, more detailed,

daily weather maps can be obtained from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., for eighty cents a month. These maps are copies of the official U. S. Weather Bureau maps. They are mailed daily to subscribers all over the country. Even though the maps arrive a day later than the weather pictured on them, they will help you to associate pressure systems and fronts with the weather that you observed at your home or school.

In addition to weather maps, *keep records* of your local weather using the instruments that you have made. Take your readings at the same time each day. Include pressure, wind direction and speed, temperature, precipitation and humidity. As your records grow, you will learn to associate certain combinations of pressure, temperature and wind with the approaching weather. Your growing skill at short-range forecasting may surprise you.

Some Helpful References

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BLUMENSTOCK, DAVID, THE OCEAN OF AIR, *Rutgers University Press, New Brunswick, N. J., 1959. 440 pages.* A comprehensive account of the nature of the atmosphere and its effect on weather, climate, and commerce. Useful both as a reference and descriptive account. Advanced readers and their teachers.

FISHER, ROBERT M., HOW TO KNOW AND PREDICT THE WEATHER, *Mentor Books, New York, 1953. 162 pages.* A pocket book on weather in pocket book size. Contains sections on air masses, fronts, interpretation of newspaper weather maps, and amateur forecasting. Advanced readers and their teachers.

LAIRD, CHARLES AND RUTH, WEATHERCASTING, *Prentice-Hall, Englewood Cliffs, N. J., 1955. 151 pages.* A simplified introduction to weather forecasting by the layman, using basic commercial or home-made instruments. Better for description of techniques than for practicality of instrumentation. Advanced readers and their teachers.

WEATHER FORECASTING, *U. S. Weather Bureau, Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. 39 pages.* Elementary principles of weather forecasting, with explanations of maps, their analysis, and a brief section on local weather signs. Advanced readers and their teachers.

WEATHERWISE, *American Meteorological Society, 45 Beacon St., Boston 8, Mass.* A bi-monthly periodical containing interesting, useful, and up-to-date accounts of weather phenomena and practices. Advanced students and their teachers.